

# FACTORS CONTROLLING STRESS RUPTURE OF FIBER-REINFORCED CERAMIC COMPOSITES

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## INTRODUCTION

The successful application of fiber-reinforced ceramic matrix composites (CMC) depends strongly on maximizing material rupture life over a wide range of temperatures and applied stresses. The objective of this paper is to examine the various intrinsic and extrinsic factors that control the high-temperature stress rupture of CMC for stresses below and above those required for cracking of the 0° plies (Regions I and II, respectively). Using creep-rupture results for a variety of ceramic fibers and rupture data for CMC reinforced by these fibers, it is shown that in those cases where the matrix carries little structural load, CMC rupture conditions can be predicted very well from the fiber behavior measured under the appropriate test environment. As such, one can then examine the intrinsic characteristics of the fibers in order to develop design guidelines for selecting fibers and fiber microstructures in order to maximize CMC rupture life. For those cases where the fiber interfacial coatings are unstable in the test environment, CMC lives are generally worse than those predicted by fiber behavior alone. For those cases where the matrix can support structural load, CMC life can even be greater provided matrix creep behavior is properly controlled. Thus the achievement of long CMC rupture life requires understanding and optimizing the behavior of all constituents in the proper manner.

## EXPERIMENTAL

For applied stresses within Region II, CMC rupture life at high temperatures is controlled by the time-dependent fracture of the fiber bundles that bridge the matrix cracks and are thus exposed to the CMC service environment. To simulate this condition for an oxidizing environment, a variety of oxide and non-oxide fiber types were stress-rupture tested as single fibers under constant load in air between 800 and 1400°C. The rupture time results versus applied stress and temperature were analyzed using thermal activation theory in order to develop single master curves for fiber rupture strength. Fig. 1 shows master rupture curves for four fiber types of current interest for CMC reinforcement. The rupture time/temperature data are contained in the  $q$  parameter with time in hours and temperature in kelvin. Clearly there are significant differences in the rupture behavior that depend on such intrinsic factors as fiber composition, grain size, and grain boundary phases. The practical significance of these curves is that they can be converted, using simple rule-of-mixtures theory, into predictions of maximum CMC strength capability versus rupture time and temperature. This is shown by the solid line in Fig. 2 where Region II conditions are assumed in air for a 0/90° CMC with 20% Hi-Nicalon fiber in the applied stress direction. It is shown using literature data that this approach gives fairly accurate predictions for a variety of different CMC tested under the assumed conditions. Exceptions, in terms of worse behavior than the predictions, were found only for those CMC systems with strong bonding and/or environmentally unstable interfacial coatings.

For applied stresses within Region I, the un-cracked matrix can provide some load-carrying ability that can reduce the effective stresses on the fiber. At high temperatures, the matrix load will generally depend on the matrix stress-relaxation or creep characteristics so that, like the fiber, microstructural factors such as matrix composition, grain size, and grain boundary phases become important. Examples will be presented on how these factors can vary widely

for current matrix types. However, if judiciously selected, the fiber stresses can be kept low so that long-life Region I behavior might be expected. This is illustrated by the hashed area in Fig. 2 where cracking is assumed above ~70 MPa for a CVI SiC matrix. Region I CMC data from the literature are examined to discuss the importance of matching fiber and matrix creep behavior. These data will also be used to develop some general relationships between CMC rupture and fiber creep and rupture within an un-cracked matrix.

## SUMMARY AND CONCLUSIONS

This paper demonstrates that fiber-creep-rupture behavior measured on single fibers can be used to predict the stress-rupture performance of various CMC for a variety of potential high-temperature applications. The important intrinsic and extrinsic factors controlling this behavior are discussed and illustrated with property data for fibers and CMC of current technical interest. In some cases it is shown that environmental characteristics of the interface as well as the creep characteristics of the matrix can also play important roles. With this understanding, general guidelines are then developed for maximizing CMC rupture life either by using the best constituents currently available or by microstructural design of advanced constituents.

Fig. 1. Master curves for rupture strength of oxide-based Nextel 610 and 720 fibers and SiC-based Hi-Nicalon and Sylramic fibers

Fig. 2. Predicted rupture strength behavior for a 0/90 CMC containing 20% Hi-Nicalon fiber in the applied stress direction. (-----): matrix cracked in air above 70 Mpa. (- - - -): un-cracked matrix with proper creep properties.

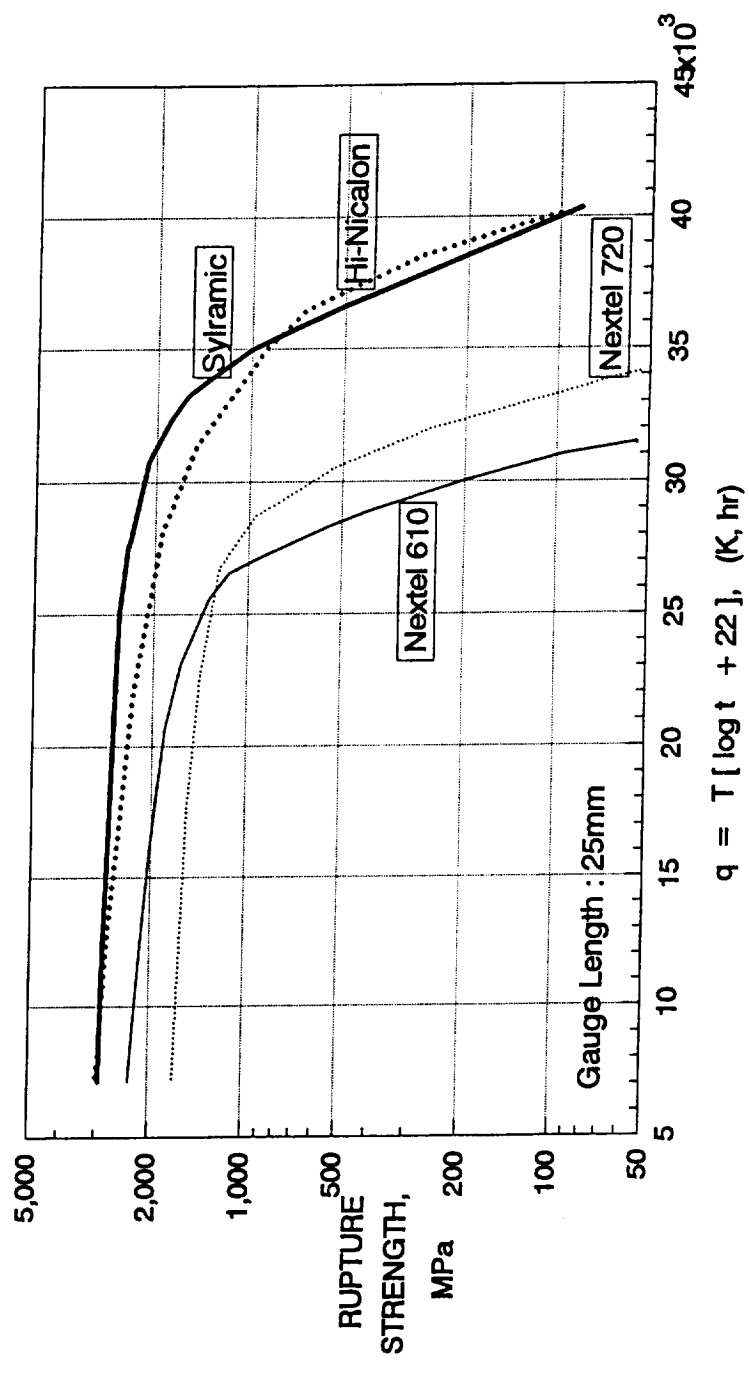


Fig. 1

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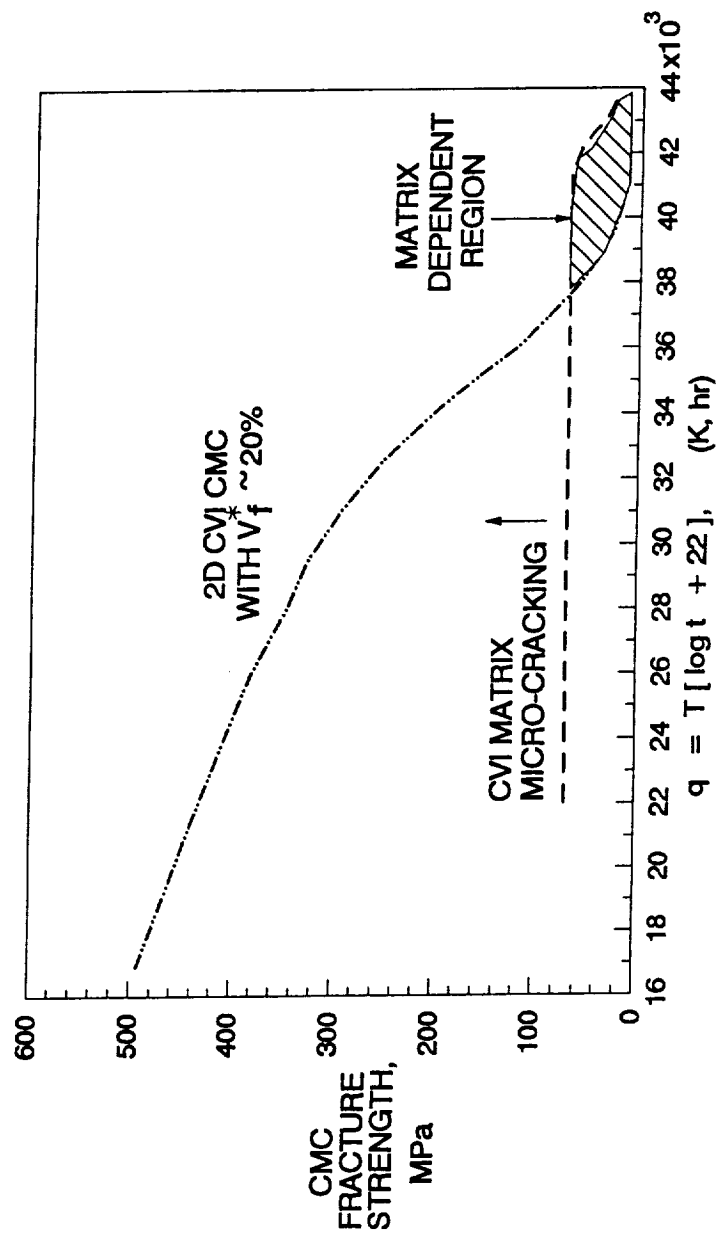


Fig. 2